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EPA'S PROGRAM FOR EVALUATION AND DEMONSTRATION OF LOW-COST RETROFIT LIMB TECHNOLOGY

By

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16. ABSTRACT The paper discusses program objectives, approaches, current status and results, future activities, and schedules for EPA's program for research and development, field evaluation, and demonstration of Limestone Injection Multistage Burner (LIMB) technology. Primary emphasis is on: (1) the full-scale demonstration being conducted on Ohio Edison's 104 MW wall-fired Edgewater Station Unit 4; (2) evaluation on a 50 million Btu/hr tangentially fired prototype which is nearing completion; and (3) on-going field evaluation on Richmond Power and Light's 61 MW tangentially fired Whitewater Valley Generating Station Unit 2. The new program for demonstration on Virginia Electric Power's 180 MW tangentially fired Yorktown II Plant is also described. The LIMB process is based on injecting dry sorbents into the boiler for direct capture of SO2 from the combustion gases. LIMB combines sorbent injection for SO2 control with the use of low-NOx burners, in which staged combustion is utilized for NOx control. Control techniques for acid rain will likely include a combination of technologies to achieve the mandated pollutant reduction at a cost that will minimize the impact on the nation and on specific geographical areas. Analysis indicates that low capital cost technology for retrofit to existing boilers would provide flexibility in controls even at moderate SO2 removal rates.

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Limestone	Nitrogen Oxides	Stationary Sources	08G	
Sorbents	Humidification	Limestone Injection	11G	13H
Injection	Boilers	Multistage Burners	14G	13A
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INTRODUCTION(1)

Sulfur oxide (SO_2) and nitrogen oxides (NO_x) are two major pollutants resulting from the combustion of fuels. Coal-fired utility boilers account for about 70% of the SO_2 and 20-25% of the NO_x emissions in the United States. For the 180,000 megawatts (MW) of boiler capacity east of the Mississippi River, this amounts to approximately 16 million tons (14.5 million metric tons) of SO_2 and 4-5 million tons (3.6-4.5 million metric tons) of NO_x per year.

The need for control of emission of SO_2 and NO_x from existing coal-fired utility boilers is a significant question facing the Environmental Protection Agency (EPA) and other organizations, both public and private. These two pollutants are widely believed to be the major precursors of acid precipitation. The national strategy for controlling these emissions has yet to be adopted; the debate centers on reduction of current SO_2 emissions by 5-12 million tons per year and on reduction of NO_x either as an SO_2 offset, or in its own right as related to forest damage. The selection of a strategy will determine the technology mix to achieve the emission reduction. Of the existing options, flue gas desulfurization (FGD) is costly and fuel switching may have adverse socioeconomic and/or logistic impacts. Only about 10% of the boilers east of the Mississippi are subject to New Source Performance Standard (NSPS) controls for SO_2 and NO_x. Therefore, to accomplish any significant reduction in SO_2 and NO_x requires a retrofit of existing boilers, which may have a remaining useful life of 5-30 years or more. Therefore, there is a need for low cost alternatives which are applicable to part or all of the existing boiler population. One such control option, which has shown promise in tests conducted by both EPA and industry, is the Limestone Injection Multistage Burner (LIMB) process which will simultaneously reduce both SO_2 and NO_x emissions. In this process, shown schematically in Figure 1, a sorbent is injected into the boiler at a location which will provide the optimum time/temperature for reaction to remove 50-70% of the sulfur present. The NO_x is controlled by utilizing a specially designed burner in the boiler. Two major design types must be addressed: 1) wall-fired boilers, which are manufactured by the Babcock & Wilcox Company (B&W), Foster Wheeler, and Riley Stoker; and 2) tangentially fired (T-fired) boilers, which are manufactured by Combustion Engineering. Each type is about 45% of the existing population, with up to 10% in other designs. There are significant differences in the firing system and resulting changes in combustion conditions between T-fired and wall-fired boilers (Figure 2). LIMB and related technologies, which are affected by the ability to inject and mix the sorbent with the combustion gases at the right condition, must be developed for each major type of boiler.

Objectives and Approach

The objective of the LIMB program is to demonstrate and commercialize the technology at an early date for both wall-fired and tangentially fired boilers. The performance goals within this objective are: 1) for retrofit, 50-60% reduction of both SO_2 and NO_x from controlled levels; 2) for new systems, 70-80% NO_x reduction and 70-90% SO_2 reduction from uncontrolled levels; and 3) achievement of these goals at costs at least \$100/kWh less than the major technology alternative, FGD, and 30-50% less than the cost of FGD on a per ton of sulfur removal basis.

The program has been structured to give the best possibility of achieving the stated goals with applicability to the major portion of existing boiler population. The major research objective is to provide the basis for widespread private sector commercialization based on successful demonstration on both a wall-fired and a tangentially fired boiler. An essential supporting objective is to perform the generic research and development (R&D) necessary to ensure success of the demonstrations and to maximize the sulfur capture potential of the technology. Other supporting objectives are to

integrate and generalize the R&D results with those from the demonstrations into a design methodology for assessing applicability to any given boiler and to improve the SO_2 removal efficiency to 70-90% for new sources. To achieve these goals, activity has been concentrated in four major areas:

1. R&D Support to Demonstrations - This R&D has been of a generic nature, directed toward complete and fundamental understanding of the process, and relatively independent of the hardware-specific constraints of practical boilers. In recent years, R&D emphasis has shifted to direct support for demonstrations. This current support has the objectives of 1) improving performance and/or cost effectiveness, 2) optimizing the humidification process, 3) improving electrostatic precipitator (ESP) performance, and 4) establishing environmentally acceptable waste disposal methods.

   This R&D has resulted in improved sorbent performance by screening candidate hydrates to guide sorbent selection, verifying that surfactant addition to hydrated lime increases overall SO_2 capture by 5-10%, and that recycled sorbent can be effectively reactivated. The R&D established that humidification has the potential to increase total SO_2 capture 10-20%, identified the importance of proper humidification nozzle/duct design, and provided pilot ESP evaluation of technology options at Ohio Edison's 104 MW Edgewater Station in Lorain, Ohio. In the waste disposal area, the R&D established that waste can be easily handled and showed potential for by-product utilization.

   R&D will be continued on improved sorbents and humidification and in direct support of the wall-fired demonstration at Edgewater, ESP options and design modifications will be tested, waste disposal activities will be monitored, humidification operational conditions will be recommended, and laboratory support and problem solving will be provided. Additional information on EPA's fundamental and pilot plant program is in References 2 and 3.

2. Demonstration on Wall-Fired Boilers - As stated earlier, wall-fired boilers are one of the two major types of boilers. LIMB development and demonstration on wall-fired boilers were the subject of initial activities because both the R&D background and large-scale experimental facilities were available. With a special Congressional appropriation of $5 million, the first full-scale demonstration of LIMB technology was initiated on a representative wall-fired boiler in late September 1984. This program will document emission control performance, boiler system effects operability, and costs, and evaluate humidification in combination with LIMB for enhanced SO_2 removal and improved particulate control. Start-up activities are underway at Edgewater. More details are provided later in this paper.

3. Development and Demonstration on Tangentially Fired Boilers - Special Congressional appropriations in FY 85 and 86 accelerated R&D and initiated the demonstration of this second major boiler type. This was necessary because injection and mixing of sorbents with the flue gas is significantly different from wall-fired boilers because of the vortex action produced by T-firing. Using a $6.5 million Congressional appropriation in FY 85, an R&D project to evaluate injection parameters and mixing at the 50 million Btu/hr (52.7 kJ/hr) prototype scale and a scaled-up 61 MW field evaluation, co-sponsored and co-managed with the Electric Power Research Institute (EPRI), were initiated. With a $5 million Congressional appropriation in FY 86, a 180 MW demonstration was initiated in mid-June 1987. These three programs are discussed later in this paper.

4. Process Generalization - For ultimate widespread use of LIMB technology, the R&D results must be integrated with full-scale boiler demonstration results to provide a well defined set of criteria for application of LIMB to a wide range of boiler designs, coals, and sorbents as guidance for commercialization by the private sector. Following long-term performance evaluation, both the wall- and T-fired demonstration programs include a task to prepare recommendations and guidelines for LIMB commercialization. However, a limited number of demonstrations alone may not be sufficient for widespread private sector commercialization. This element of the program includes both process analysis to evaluate applicability and economics for specific systems, and process modelling, with supporting measurements on operating boilers, to provide a

methodology useful for site-specific design decisions. Process analysis has emphasized LIMB system options for application to different boilers and for minimizing the cost per unit SO_2 removal. Process modelling has included component models for thermal history, sorbent activation and reaction, sorbent reactivation and recycle, humidification, and sorbent injection and mixing. A cost model compatible with EPRI and Tennessee Valley Authority (TVA) guidelines has been developed.[4] Integration of the component models, and ultimately with the cost model, into an overall design tool is planned.

The remainder of this paper will concentrate on the 104 MW wall-fired demonstration, 50 million Btu/hr tangentially fired prototype, 61 MW tangentially fired large prototype testing, and the 180 MW tangentially fired demonstration.

104 MW WALL-FIRED LIMB DEMONSTRATION[5]

The EPA wall-fired LIMB demonstration is a 4-year project that includes design and installation of a LIMB system at the 104 MW Unit 4 boiler at Edgewater. The project includes a full year of operating and testing to demonstrate LIMB's capabilities. EPA is sharing the cost of the project with the major project participants--The State of Ohio, Ohio Edison, and Babcock & Wilcox.

The basic goal of the LIMB demonstration is to extend LIMB technology development to a full-scale application on a representative wall-fired utility boiler. The successful retrofit of LIMB to an existing boiler is expected to demonstrate that reductions of 50% or greater in SO_2 and NO_x emissions can be achieved while maintaining boiler reliability, operability, and steam production.

Recently, the project has been expanded to include flue gas humidification as an adjunct technology to LIMB. Humidification is expected to improve utilization of the unused calcium component of the spent LIMB sorbent for downstream SO_2 removal at a low incremental cost and increase the overall SO_2 removal of the system to 60% or greater. Humidification of the flue gas will also result in improved ESP performance due to gas cooling and reduction in ash resistivity.

The demonstration project consists of several distinct phases--a preliminary phase to develop the LIMB process design applicable to the host boiler, a construction and start-up phase, and an operating and evaluation phase--as shown on the project schedule (Figure 3). The development of the Edgewater LIMB design was completed in January 1986, and construction is complete. Major boiler-related components were installed during a September 1986 boiler outage. The start-up date was June 1987, and shakedown and optimization tests are underway.

LIMB Design Issues

A primary reason for the interest in sorbent injection is that its equipment requirements are simpler than those for other control technologies. However, since sorbent injection is much more closely coupled with the boiler, it must be designed for specific boiler characteristics and for compatibility with existing operating conditions. A generalized LIMB process diagram, including the humidification addition, is shown in Figure 4.

A number of major issues have been identified as being critical to the design and operation of a successful LIMB system. For the Edgewater design, these issues are:

- Development of a fundamental understanding of reaction chemistry and kinetics to enable optimization of system conditions for maximum LIMB performance.
- Selection of a sorbent that is sufficiently reactive for the SO_2 removal objectives and which is or can be produced commercially at reasonable cost.
- Characterization of the Edgewater boiler temperature and velocity profile to identify the conditions under which injection must take place.

- Design of an injection system that will disperse the sorbent into the boiler under optimum reaction conditions.
- Selection of a burner that satisfies low-NO_x goals and is compatible with the physical dimensions and requirements of the Edgewater boiler.
- Design of a sorbent handling system that will reliably deliver an acccurate amount of sorbent to the boiler.
- Evaluation and/or modification of the particulate control system to enable collection of the increased amount of ash.
- Design of an environmentally acceptable waste handling and disposal technique.

Each of these issues is being addressed in the EPA LIMB program, with recommendations for each issue being included in the Edgewater design.

Fundamental Consdiderations

From a chemical process standpoint, sorbent injection is a complex technology that requires a reasonable understanding of the interrelationships among the various chemical and physical processes to enable design of a workable process. Several major reactions take place, the most important of which are calcination of the calcium sorbent to an active calcium oxide and sulfation of the calcium oxide with SO_2 in the flue gas to produce calcium sulfate. Sintering of the calcined material may also occur under certain conditions resulting in reduced reactivity. Rates and extent of reaction can be influenced by a number of factors, with each favored by some conditions and not by others. Research results have shown that achieving good sorbent reacivity and a high degree of sulfation is best in the temperature range of roughly 850-1250°C (1600-2300°F). Temperatures much above 1250°C (2300°F) result in sintering and subsequent sorbent deactivation. The calcination and sulfation reaction rate is too low below 850°C (1600°F) to be viable. The sulfation reaction is also highly sensitive to residence time so that determining optimum injection location is critical to the success of LIMB.

During the Dry Limestone Injection Program, back in 1970, it was originally thought that sorbent could be injected through, or in the vicinity of, the burners; however, pilot combustion study results showed that burner injection is not as effective as downstream injection. The poor performance of burner injection is thought to be due to sintering and fly ash/sorbent interactions in this temperature region. Further studies using pilot plant combustion systems have shown that the optimum injection point is at a point in the furnace where the combustion gas is approximately 1200-1250°C (2200-2300°F). In the Edgewater boiler, this point is in the upper furnace just above the furnace nose. Although offering the best temperature, this region experiences a very rapid decrease in gas temperature down to 850°C (1600°F) in the convective section. It becomes a special concern to design an injection system to achieve thorough mixing of the sorbent and combustion gases to enable reaction to take place in the short residence time available.

Sorbent Selection

Selecting an appropriate sorbent and determining the type of preparation required to produce an optimum sorbent are vital to the technical and economic viability of sorbent injection. A wide range of calcium-based materials have been evaluated, varying in calcium form and content, content of magnesium and other materials, and type and degree of preparation.

In almost all cases during pilot combustion studies, hydrated lime [$Ca(OH_2)$] sorbents performed better than lime and raw limestone sorbents. A number of candidate calcitic hydrate sorbents produced within the general geographical area of the Edgewater plant have been evaluated under combustion conditions. The results showed that there was little difference in the reactivity of the candidate sorbents. However, these and other tests indicate that the smaller (<5 μm) particles separated from a typical size distribution range of a commercial sorbent sample tend to be more reactive than larger

particles of the same sample. This has been attributed to the avoidance of pore diffusion resistance of SO_2 in the particle. Further work has shown that a number of sorbent production alternatives favor generation of smaller particle size sorbents. Preliminary studies have shown that addition of certain surfactants or dispersants to the sorbent during hydration is beneficial to the capture of SO_2. These surfactants are thought to minimize agglomeration of $Ca(OH)_2$ particles with each other and reduce the number of larger particles. Further studies are being conducted to evaluate the potential for using an enhanced hydrate as the demonstration sorbent.

Boiler Characterization

Due to the critical importance of boiler temperature and velocity profile to sorbent reactivity and sorbent mixing with combustion gases, a considerable effort was undertaken to characterize the Edgewater boiler. The work included flow characterization in a 1:15 scale acrylic model of the boiler, use of a computational boiler code to estimate temperature profiles, and direct measurement of temperature and velocity at selected points in the boiler.

Compilation and evaluation of this information show important implications for sorbent injection. The temperature zone of highest reactivity is in the upper furnace, from a plane just above the nose to a plane farther back in the convective section (Figure 5). A reduction in boiler load simply moves this zone closer to the boiler nose. Bubble streak flow visualization in the scale model showed that flow velocity increases near the nose, as would be expected, and that the flow is nearly uniform across the width of the boiler. Injection will take place at the plane of the nose in the high velocity region with sufficient injection velocity to penetrate and distribute the sorbent within the furnace. The residence time in the optimum temperature window is very short, on the order of 1 second, indicating that this boiler will be a rigorous test for sorbent injection.

Sorbent Injection

The design of an effective sorbent injection system will ensure rapid dispersion at approximately 1250°C (2300°F) for maximum reactivity and maximum time in the reaction zone. While considerable progress has been made in predicting penetration and distribution patterns for various injection schemes, the relationship between sorbent distribution and sulfur capture is less predictable. Based on present understanding, development of an optimum injector design is an iterative process based on use of a combination of predictive tools and experimental investigation aimed at getting an even distribution of sorbent across a plane in the boiler. Based on boiler geometry and operating characteristics, a number of practical injection designs can be considered and refined using predictive techniques. The most promising injection combinations can then be evaluated experimentally using scaled down boiler models to select an injection scheme that will give an optimum mixing pattern in the boiler. An acrylic 1:15 scale model of the Edgewater boiler was used in cold flow injection studies.

Based on the Edgewater boiler geometry, boiler combustion air limitations, and expected injection patterns, a flexible injection scheme has been installed which will provide the ability to inject at three levels in the boiler--at the nose level, and two levels above the nose. Only two injection levels will be operable at one time. Each level will have a row of eight injector ports on the front wall; the middle level will also have two injector ports on each side wall. Provision has been made for variable injection velocities and the ability to tilt the injectors at the two upper levels 30° down from horizontal.

Burner Selection

The NO_x control component of LIMB at the Edgewater site is being implemented by replacement of the existing B&W circular burners with low-NO_x burners in which peak flame temperatures are lowered to reduce NO_x formation. A number of commercial low-NO_x burners are available, but B&W burners were preferred because of their compatibility with existing burner openings and boiler peripherals. Objectives for the burner were to reduce the NO_x emissions level to approximately 129-172 ng NO_x/J (0.3-0.4 lb $NO_x/10^6$ Btu), produce a flame length of less than 6.7 m (22 ft) to

avoid flame impingement on the back wall, and operate with a secondary air pressure drop of less than 1.5 kPa (6 in. of water) to avoid costly changes in existing fan equipment.

Although a B&W Dual Register Burner (DRB) is commercially available for low-NO_x emissions, there was a question about this burner's ability to operate within the restricted front-to-back-wall distance available for flame length. A 3-month screening test program, using a single burner, was conducted on EPA's Large Watertube Simulator (LWS) using the DRB and two other burners--a Babcock-Hitachi burner and a new B&W burner, designated the XCL. The Babcock-Hitachi burner, a new design now in commercial operation in Japan, is reported to produce very low NO_x emission, while the XCL burner is aimed at emissions comparable to those achieved by the Japanese burner. All three burners were designed for 9 MW (79×10^6 Btu/hr) to match the output of a single burner in the Edgewater boiler.

The screening tests showed the difficulty of fully meeting all criteria for the Edgewater application. Table 1 summarizes representative data on these three burners. The DRB used the same throat size as the other burners which resulted in lower than standard velocities. The DRB consequently produced unusually long flames and low NO_x levels.

The flame length criterion can be achieved by use of an impeller which markedly increases NO_x. The Hitachi burner can operate at low NO_x levels with satisfactory flame length, but the secondary air swirl required for shorter flames is achieved at the expense of high pressure drop. The XCL burner, by adjusting an impeller, can vary NO_x emissions and flame lengths at moderate pressure drops. The choice was made to proceed with the XCL burner as the burner of choice in the design. These burners have been installed and are achieving levels of 159-202 ng NO_x/J (0.37-0.47 lb $NO_x/10^6$ Btu) during shakedown testing.

Material Handling

An important aspect of the LIMB design is the specification of equipment and facilities for storage, handling, transporting, and feeding sorbent to the boiler. For the Edgewater demonstration, it was specified that the material handling system be capable of delivering up to 9.1 metric tons/hr (10 tons/hr) of sorbent to the boiler with the flexibility of handling both fine hydrated lime and coarse limestone. Important considerations in the design were mechanical reliability, prevention of line and equipment pluggage, accurate feed control, and uniform distribution to the injectors.

In the proposed material handling system, sorbent is delivered by truck to the plant and pneumatically transferred to a ground level storage silo. The stored sorbent is transferred by compressed air to a sixth-floor-level feed silo as needed. The storage silo has an aerated bin bottom, and the feed silo has a bin vibrator to promote sorbent flow. All conveying aeration air is dried to minimize moisture in the system. From the feed silo, a controlled feed rate of sorbent is provided to each of the two injection levels in use. Each level has its own independent feed system with a weight loss differential feeder which can provide a sorbent feed rate to within $\pm$ 1% accuracy. The high elevation of the feed silo promotes smooth sorbent flow by minimizing upward and horizontal lines in the delivery system. Dried conveying air is supplied through rotary valves to convey the sorbent to a distributor bottle for each level. The bottles (Figure 6) distribute the mixture into the designated number of injection lines which transport the mixture to the boiler. At the boiler, a booster air fan provides injection air through the outer portion of a concentric injector nozzle to carry the sorbent into the boiler with the required penetration and dispersion.

Particulate Control

Although the LIMB technology is not a scheme for controlling particulate emissions, particulate control is an important consideration in all LIMB applications. In this regard, there are three concerns with the LIMB process--the loading may increase by a factor of two to three, the ash resistivity may increase 100-fold, and the mean particle size will be lowered--all of which make particulate control more difficult. These effects are of special concern in retrofit applications where existing electro-

static precipitators (ESPs) are designed to meet applicable mass emission rate and visibility regulations without sorbent addition.

The Edgewater ESP is atypical for boilers of the Edgewater vintage in that it was retrofitted to the unit in 1982 and is substantially oversized for its present duty. Estimates indicate that existing emission standards can be met with this ESP even with LIMB addition. Other boiler LIMB retrofits may, however, have to consider construction of additional ESP area, prechargers, and/or gas conditioning (humidification, SO_3 addition) to remain within existing emission requirements.

The test plan for the demonstration will include a time period in which the ESP operation will be altered to simulate a marginal ESP to permit a more general assessment of LIMB effects on the ESP. Construction and operation of the flue gas humdification system just before the ESP will also develop further information on the effects of gas conditioning.

Waste Handling and Disposal

Application of LIMB creates an additional waste load and a change in ash properties. The present Edgewater waste handling and disposal system is a dry system in which ash is pneumatically removed from the ESP bottom to an ash silo, sprayed with a small amount of water in a pug mill for dust control, and trucked to a nearby landfill. In order to verify that the LIMB ash could be processed in the existing equipment, several truckloads of ash material generated during lime injection at a Canadian power plant were transported to the Edgewater plant and processed through the silo-pug mill system. The Canadian material was similar to the ash expected at Edgewater, but had a slightly lower free lime content. It was found that the lime in the ash could be neutralized (hydrated) in the pug mill and a dust-free material could be produced for truck hauling to a landfill. Control of water amount and rate were found to be critical to avoid pug mill pluggage and hardening of the material in the truck.

Testing of LIMB waste under conditions specified in the Resource Conservation and Recovery Act (RCRA) showed (Table 2) that leachable toxic materials were far below levels considered to be hazardous, that rain runoff from the stored material would appear to meet required pH levels, and that ignitability and reactivity are not a problem. Current plans are for the LIMB-modified ash to be disposed of in an existing landfill but separated from conventional ash storage for observation and testing.

An active effort is being made by EPA and others to produce a salable product from the LIMB waste, including pelletizing into a usable aggregrate, neutralization of acidic wastes, and recycle of unreacted sorbent back to the LIMB process, all with the aim of reducing process costs. Additional details regarding these efforts may be found in Reference 7.

Discussions with the Electric Power Research Institute (EPRI) and the Department of energy (DOE) have started to plan a joint evaluation of the waste handling and disposal system during the demonstration to ensure that any potential problems are resolved and a generic data base is developed for related applications.

As one of the nine projects selected under the Clean Coal Technology Program, DOE has selected an extension to the LIMB wall-fired demonstration at Edgewater. This approximately 42-month program will provide a by-pass duct for EPA's humidification testing, an additional year of LIMB testing with up to 12 sorbent/coal combinations which include humidification and simulated sorbent recycle, and an evaluation of CONOCO's coolside technology.

50 MILLION BTU/HR TANGENTIALLY FIRED LIMB PROTOTYPE TESTING(6)

This EPA program is being performed by Combustion Engineering at C-E's Kreisinger Development Laboratory (KDL) in Windsor, Connecticut, to develop criteria for the location and method of sorbent injection into tangentially fired coal-burning utility boilers. The program includes four tasks with the following objectives:

TASK A - Evaluate sorbent injection locations and methods in a cold-flow facility which simulates C-E's tangentially fired 50 million Btu/hr Boiler Simulation Facility (BSF).

TASK B - Recommend sorbent injection locations and methods by applying mathematical modelling to Task A data with consideration of sorbent activation and residence time at sulfation temperature.

TASK C - Test sorbent injection location/injector design combinations in the BSF.

TASK D - Recommend sorbent injection system design criteria for a full-scale tangentially fired boiler demonstration.

Tasks A and B are essentially complete, and technical work on Task C is nearing completion. The Task D effort has begun. Tasks A, B, and C are discussed below.

Cold Flow Modelling Approach

Task A, cold flow modelling, consisted of three screening levels designed to lead to the selection of injector design/location combinations for combustion testing. In the first screening level, flow visualization tests of 16 configurations at simulated full load furnace operating conditions were conducted. Each configuration was evaluated at up to three injector carrier air velocities, for a total of 46 injection schemes.

The 11 best injector configurations from the first screening level were then evaluated in the second screening level, which consisted of three-dimensional velocity profile measurements and mixing studies using a methane tracer gas measured by a laser absorption spectrophotometer. In the third screening level, the five configurations which demonstrated the best performance in the second level testing were tested over a range of simulated furnace operating conditions using the same techniques utilized during the first two screening levels.

Isothermal flow modelling was performed in the Large Scale Furnace Aerodynamics Test Facility (LSFATF) located at KDL. For this program, the facility was converted into a 0.46-scale simulation of the BSF. Built primarily of clear plastic, the model encompasses the entire furnace from the hopper to the economizer outlet. The windboxes were designed to permit adjustment of the tangentially fired fuel admission assemblies including tilt, offset, air staging, and overfire air. Upper furnace radiant and convective heat transfer surfaces are also modeled. A header system provides controlled introduction of smoke particles or tracer gas to any one or a combination of simulated sorbent injectors.

Surrounding the furnace model is a three-axis instrument traversing system which allows the placement of instrument packages, including a five-hole pitot tube, a laser doppler anemometer, and a laser absorption spectrophotometer.

Injector locations were selected to provide generalized design data for the full range of utility boilers. The locations of injector configurations are identified in Table 3 and shown in Figure 7.

Using a new jet modelling technique which allows a two-phase jet issuing into a hot environment to be modeled isothermally by a single-phase gas-only jet, a large number of sorbent injection sysems were evaluated in the multi-level screening process. A restricted number were recommended for the sulfation temperature window expected in the BSF. From the 46 initial injection schemes evaluated, about 30 combinations of location, injection velocity, and injection angle were selected for Task C combustion testing in the BSF.

Task B - Mathematical Modelling

Mathematical modelling was conducted in two areas. One was thermal modelling to identify the preferred location in the furnace for sorbent injection and to provide furnace time/temperature profiles. The second was SO_2 capture performance modelling, which ultimately will be used to make SO_2 capture performance predictions and performance guarantees. Over the shorter term, the modelling will be used to interpret test results and to provide recommendations for further development testing.

Task C - Combustion Testing

Combustion testing will apply sorbent injection techniques developed under Task A (Flow Modelling) and Task B (Mathematical Modelling) in the pilot-scale tangentially fired BSF operating at 50 million Btu per hour (14.7 MW thermal). A number of injector design/location combinations are being tested over a range of furnace and injector operating conditions. Three sorbent types will be evaluated.

The BSF accurately models the time/temperature history, heat release rate, heat absorption, and aerodynamic characteristics of a large utility boiler (Figure 8). All major aspects of a utility boiler are duplicated, including the lower furnace, the ash hopper, multiple burners, the arch section, superheater panels, and the convective heat transfer surfaces. The BSF is top-supported like a typical utility boiler.

The BSF is fully instrumented to monitor combustion phenomena. Access ports are located throughout the furnace and convective sections for temperature and velocity measurements, for particulate sampling, and for flue gas sampling. Optical access ports are also distributed at selected locations around the facility for visual observations.

Construction of and commissioning tests in the facility were completed and sorbent injection performance testing began in April 1987. Three hydrate sorbents and Pittsburgh No. 8 coal will be utilized during the combustion testing.

A project final report is anticipated in the Fall of 1987.

61 MW TANGENTIALLY FIRED LIMB LARGE PROTOTYPE TESTING

The U.S. Environmental Protection Agency and the Electric Power Research Institute are co-sponsoring and co-managing a 4-year program to evaluate sorbent injection technology on a tangentially fired utility boiler.

The host utility for this program is Richmond Power & Light's Whitewater Valley Generating Station, Unit 2, in Richmond, Indiana. This unit is a 61 MW tangentially fired utility boiler constructed in 1973 (pre-NSPS) and was retrofitted in 1980 with the low-NO_x concentric firing system (12 burners). This unit is equipped with a Lodge Cottrell cold-side precipitator (SCA = 198) and also utilizes a Lungstrum air heater.

This program includes a 3-phase field evaluation; each phase represents the evaluation of a sorbent injection technology. The objectives of the overall program are:

1. To provide a utility-scale boiler which can be utilized to support an R&D testing program.

2. To provide a testing program to measure the relationship between SO_2 capture performance and different injection schemes using various coals, sorbents, and loads.

3. To evaluate the impact of LIMB technology on boiler performance and operability by testing over a wide range of conditions representative of U.S. utility boilers.

4. To provide a data base which can be used directly by the utility industry to apply these technologies to meet projected emission reduction requirements at minimum total cost.

Phase I, the initial field evaluation, will involve upper furnace injection of calcium based sorbents with humidification upstream of the ESP to enhance ESP performance (see Figure 9). The second and third field evaluations (Phases II and III) will be based on the status of the technology at that time.

Each phase will focus on one specific injection technology and will consist of 4 months of testing. Each 4-month testing period will be divided into 2 months for parametric testing, 1 month for optimization testing, and 1 month for long-term operational testing.

To support the application of LIMB technology, many activities to characterize the RP&L boiler have been completed. To support the upper furnace sorbent injection design, field measurements of temperature and velocity have been made, an isothermal model has been constructed, and heat transfer and jet mixing and dispersion models using RP&L conditions have been applied. These methodologies have been utilized to develop representative temperature and velocity profiles of the RP&L boiler and to support the design and development of the sorbent injection system for RP&L conditions.

Similar activities have been completed to support the humidification design. Field measurements of temperature and velocity have been made within the duct, an isothermal model of the duct has been constructed, and evaporation models have been using the RP&L conditions. In addition, an extensive nozzle evaluation program has been completed to support the design of the humidification spray assembly.

The engineering design and equipment procurement of the sorbent injection and humidification system have been completed. The equipment is currently being installed. Shakedown will follow, and Phase I LIMB testing is scheduled for September 1987.

The current schedule is to begin the parametric testing in mid- to late-September of this year. The optimization testing will be run from December 1987 to January 1988. Allowing for review and analysis of the test results and to prepare for the long-term testing, the 30-day operational test is currently planned for February 1988.

180 MW TANGENTIALLY FIRED LIMB DEMONSTRATION

EPA initiated demonstration of LIMB technology on a tangentially fired utility boiler on June 12, 1987, with the signing of a contract with Combustion Engineering as the prime contractor. Over 50% of the program value is being provided by the industrial partners which include Combustion Engineering, Virginia Power Company, and Radian Corporation. Other industrial partners include Stone and Webster Corporation and C-E Lummus. The Government share of the funding is being provided by EPA and the Department of Energy.

The objective of this program is to demonstrate greater than 50% reduction in SO_2 and NO_x emission levels at a fraction of the cost of add-on flue gas desulfurization systems, long-term boiler reliability at a level which existed prior to retrofit of the sorbent injection system, and cost-effective resolution of potential technical difficulties attributable to sorbent injection operation such as additional slagging and fouling, changes in ash disposal requirements, and an increase in particulate load. In addition to demonstrating LIMB, the program will also evaluate the SO_2 removal enhancements achievable with flue gas humidification and sorbent reactivation and recycle.

The demonstration site is the 180 MW coal-fired Yorktown Unit 2 of Virginia Power Co. in Yorktown, Virginia. An intermediate sulfur content coal (about 2%) will be fired during the demonstration program. The T-fired demonstration is expected to span a total period of about 5 years, of which about 1 year will be dedicated to the LIMB performance evaluation.

The T-fired demonstration program consists of:

Task 1 : Perform Program Management
Task 2 : Develop Preliminary LIMB Concept
- 2A: Conduct site-specific preliminary studies
- 2B: Develop demonstration performance objectives
- 2C: Prepare preliminary process design
- 2D: Prepare preliminary cost estimate
- 2E: Prepare demonstration schedule
- 2F: Present preliminary integrated LIMB concept for EPA evaluation

TASK 3 : Determine Baseline Conditions
- 3A: Develop test plan
- 3B: Conduct baseline tests

TASK 4 : Conduct Demonstration Program
- 4A: Prepare detailed engineering design

4B: Procure, install, and construct equipment
4C: Operate system
4D: Evaluate performance
Task 5 : Prepare Recommendations and Guidelines for LIMB Commercialization
Task 6 : Restore Site

The demonstration program field testing will be supported by mathematical modelling and pilot-scale testing at KDL. These pilot-scale investigations will include aerodynamic flow modelling and testing on the 50 million Btu/hr BSF. Following boiler characterization activities, these facilities will be modified to the configuration of the Yorktown Unit 2 boiler. In addition, intermediate scale combustion tests will be conducted to evaluate the impact of sorbent injection on heat transfer surface fouling and erosion and to evaluate the effect of sorbent injection and SO_2 capture on ESP performance.

At this writing, the detailed work plan has not yet been prepared. However, it is estimated that the preliminary integrated concept will be available for EPA review about April 1989 and equipment installation, construction, shakedown, and debugging will be completed about July 1990, at which time performance evaluation will be initiated and, including long-term operation, will be complete by late 1991. A final report is anticipated by mid-1992.

ACKNOWLEDGEMENTS

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TABLE 1

BURNER TEST RESULTS

Burner	NO_x ng/J (lb/10^6 Btu)	Flame Length m (ft)	Windbox Pressure kPa (in. H_2O)
DRB	107 (0.25)	>6.7 (>22)	1.1 (4.6)
	356 (0.83)	5.5 (18)	1.5 (6.0)
Hitachi	145 (0.34)	6.1 (20)	1.9 (7.5)
	125 (0.29)	5.8 (19)	3.3 (13.2)
XCL	126 (0.29)	>6.7 (>22)	1.4 (5.5)
	197 (0.46)	6.1 (20)	0.9 (3.5)
	231 (0.54)	4.9 (16)	1.4 (5.5)

TABLE 2

LEACHATE DATA FOR SIMULATED LIMB DEMONSTRATION WASTE PRODUCTS

Metal	Allowable Limit Per RCRA*	Demo Coal/ Hydrate A*	Demo Coal Hydrate B*
Arsenic	5	0.0145	0.0210
Barium	100	4.11	4.24
Cadmium	1	0.00095	<0.0005
Chromium	5	0.0394	0.0240
Lead	5	<0.0030	0.0045
Mercury	0.2	<0.0003	<0.0003
Selenium	1	0.0296	0.0228
Silver	5	<0.0005	<0.0005
pH	12.5	(12.4/12.2)†	(12.4/12.2)†

* Concentration in extract in mg/l.
† Before/after acetic acid addition per the Extraction Procedure (EP) Toxicity Test.

TABLE 3

FIRST SCREENING LEVEL TEST CONFIGURATIONS (SEE FIGURE 7)

Configuration	Location	Description
1	A	Above arch, low, along front wall
2	B	Above arch, mid, along front wall
3	C	Above arch, high, along front wall, -45° tilt
4	A,B	Combination of Configurations 1 & 2
5	B,C	Combination of Configurations 2 & 3
6	A,C	Combination of Configurations 1 & 3
7	A,B	Combination of Configurations 1 & 2 Location A with high velocity Location B with low velocity
8	D	Under arch, T-fired corotational
9	D	Under arch, T-fired counterrotational
10	E	Under arch, along back wall
11	E,B	Under arch, along back wall combined with above arch, along front wall
12	F	Roof mounted
13	A,F	Four above arch, low, along front wall with four roof mounted
14	H	Roof mounted, single port, vertical hanging lance, low position, and 90° tilt
15	G	Roof mounted, hanging lance, high position, and -45° tilt
16	H,C	Roof mounted, single port, vertical hanging lance, combined with front wall, high

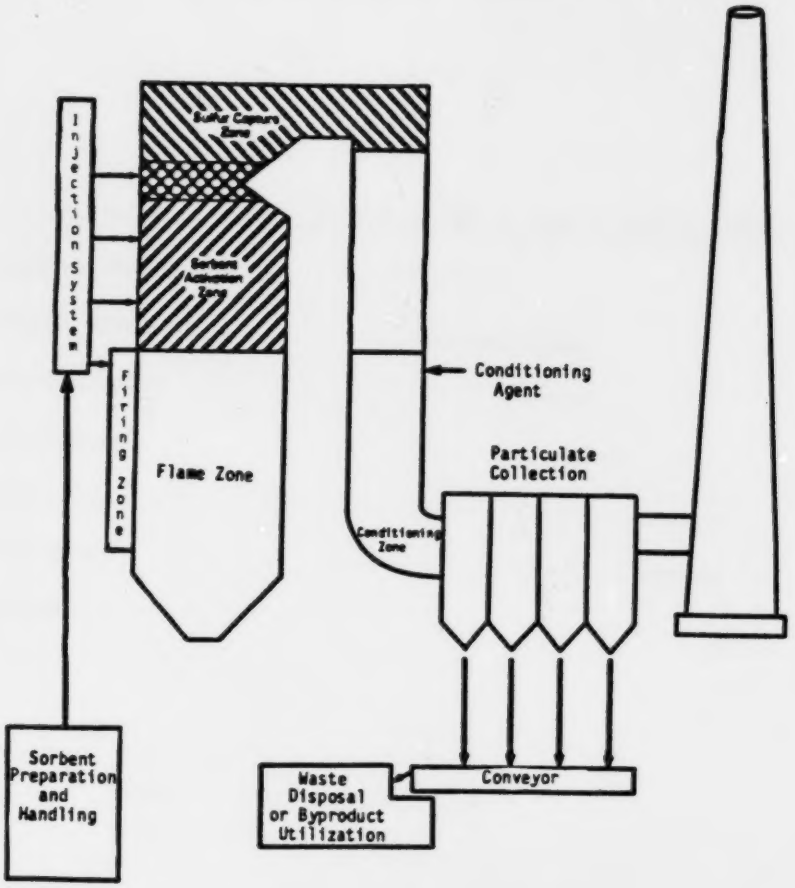

Figure 1. Schematic of Integrated LIMB System

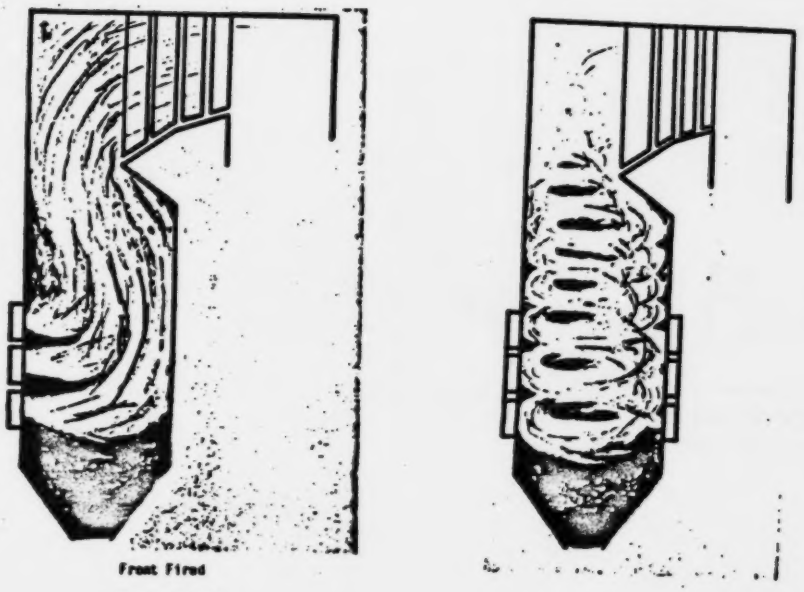

Figure 2. Boiler Flow Fields

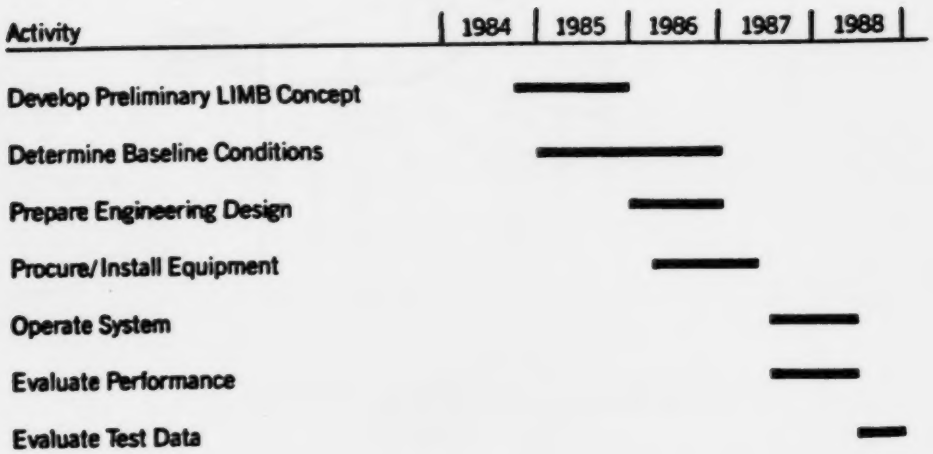

Figure 3. Project Schedule

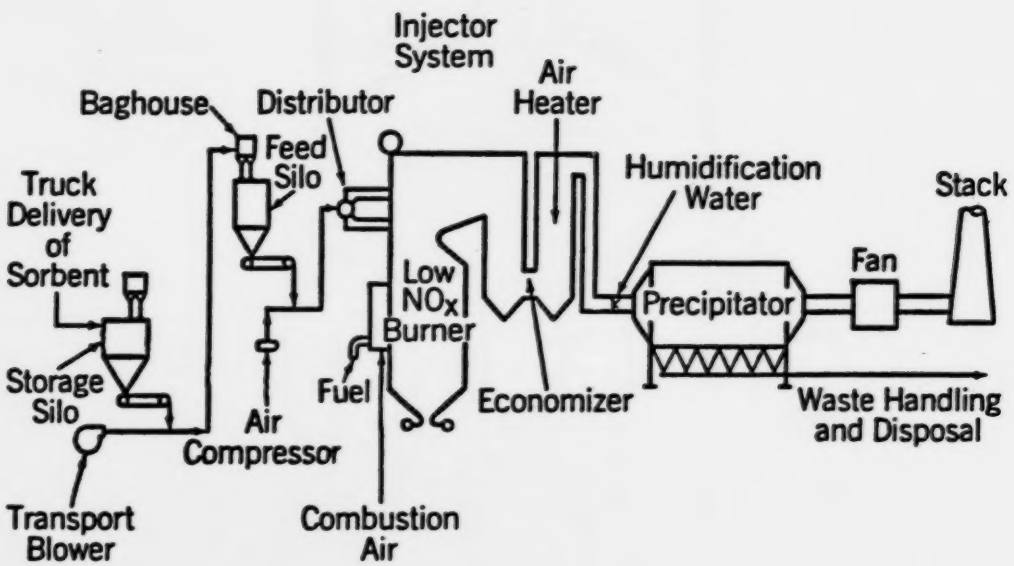

Figure 4. LIMB/Humidification Process Diagram

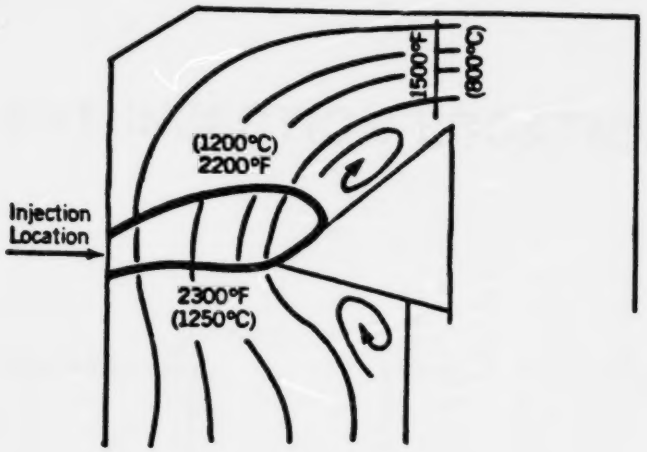

Figure 5. Location of Sulfation Temperature Window and Estimated Flow Pattern in Edgewater Boiler

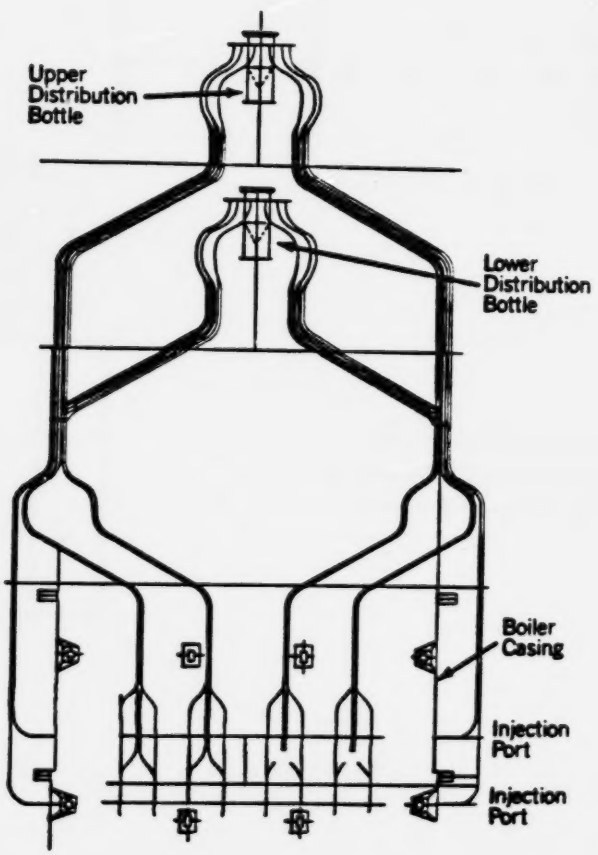

Figure 6. Sorbent Distribution System

SORBENT INJECTION LOCATIONS

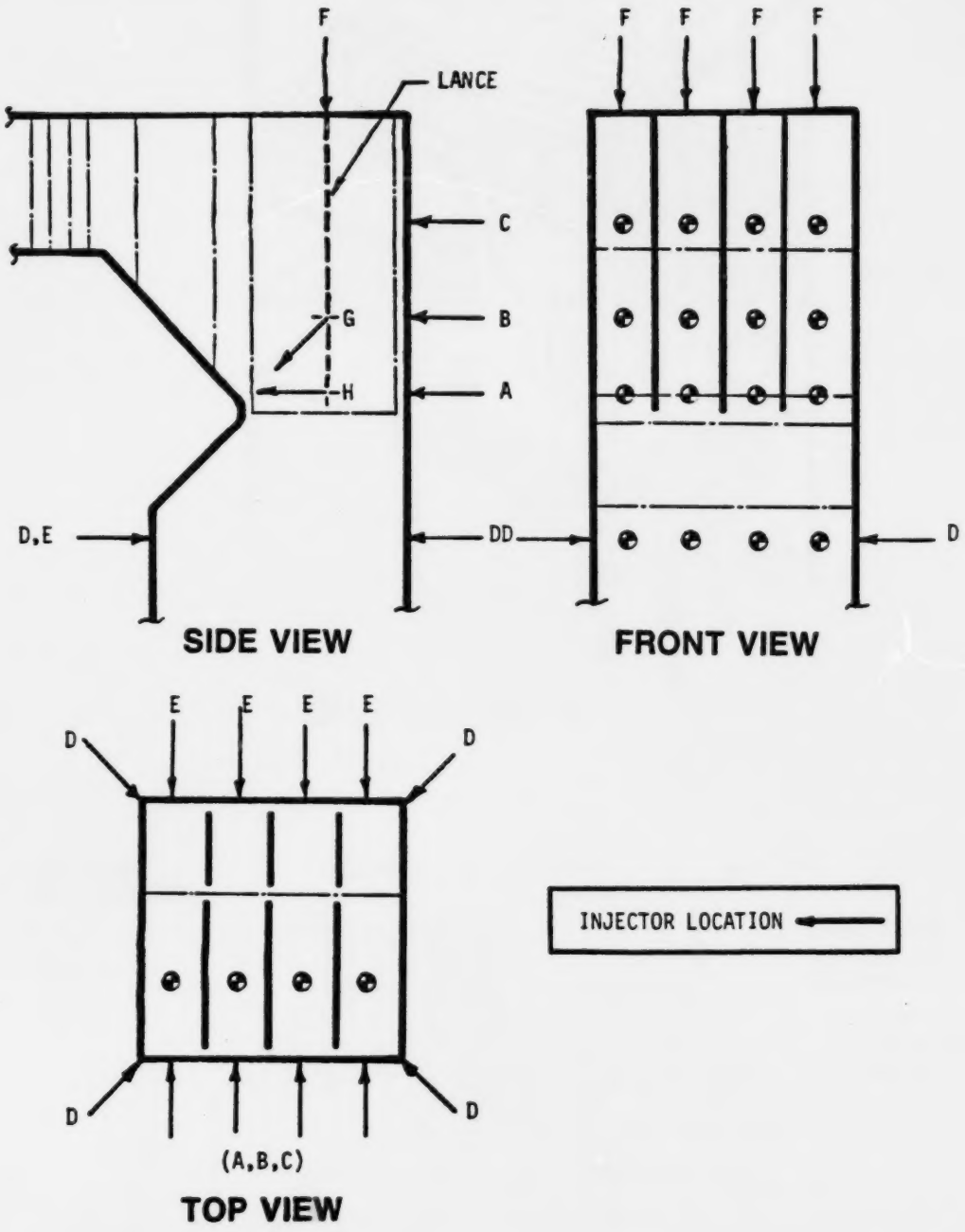

Figure 7. Furnace Model Sorbent Injection Locations (See Table 3)

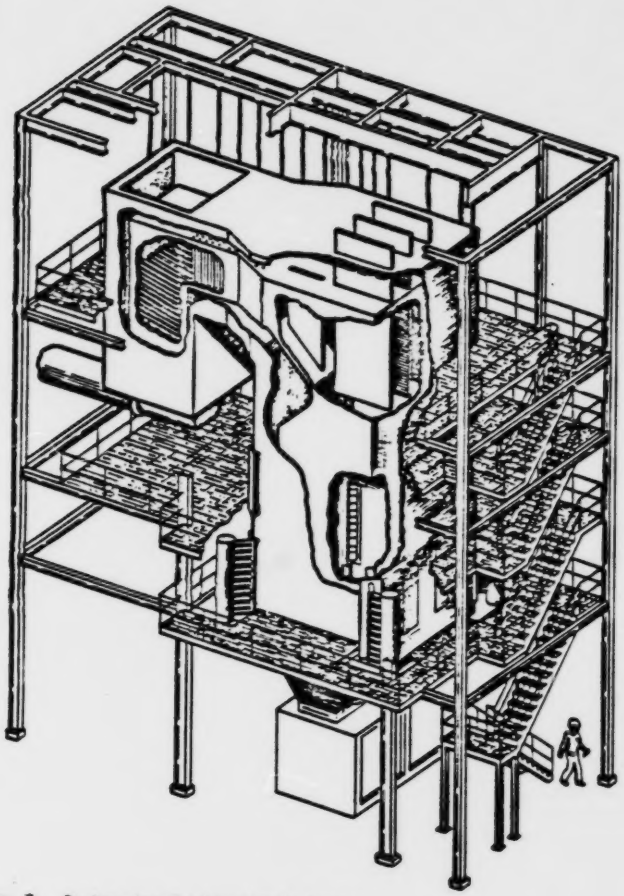

Figure 8. Combustion Engineering's Boiler Simulation Facility (BSF)

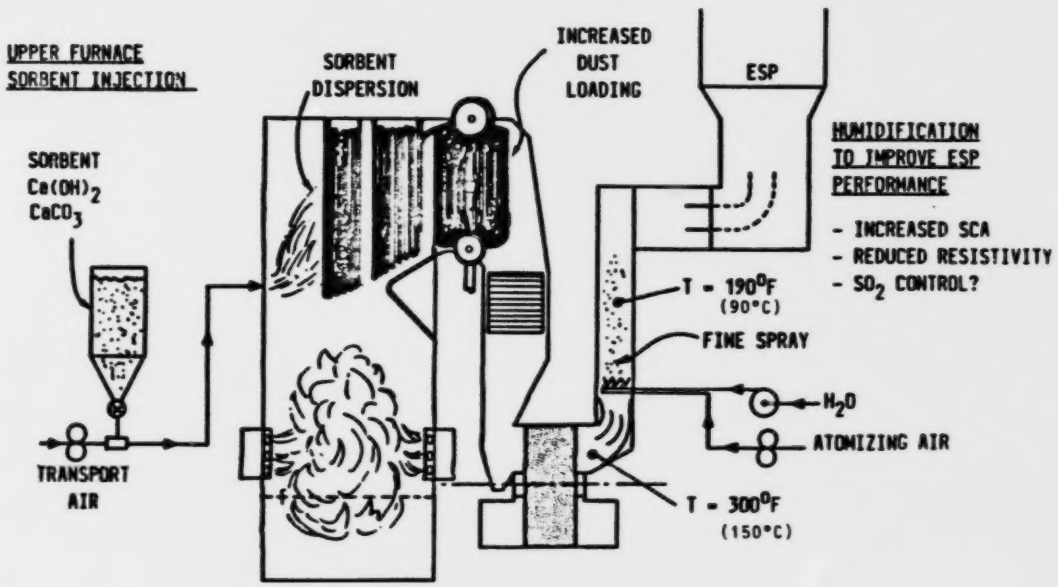

Figure 9. Phase I Sorbent Injection With Humidification for ESP Improvement